Health Impact Assessment of PM10 and PM2.5 in 27 Southeast and East Asian Cities

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Title Page

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Health impact assessment of PM_{10} and $PM_{2.5}$ in twenty-seven Southeast and East Asian cities

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Conflicts of interest statement:

None declared.

Abstract

Objective

We aimed to evaluate the annual health impacts of particulate matter (PM) <10 μm diameter (PM_{10}) and <2.5μm diameter ($PM_{2.5}$) in 27 cities in Southeast and East Asian countries (the Philippines, the Republic of Korea, Singapore, and Viet Nam) for the year 2009 (n= 50,756,699).

Methods

We estimated the number of cases attributable to long-term exposure. We used a scenario that reduced the annual mean values for PM_{10} and $PM_{2.5}$ to 20 and 10 μg/m^3, respectively.

Results

A reduction in long-term exposure to PM_{10} and $PM_{2.5}$ would have postponed 8–9% of all-cause mortality, or about 37,000 deaths. One-third of them were associated with cardiopulmonary mortality and one-ninth of them were associated with lung cancer mortality.

Conclusions

Current air pollution levels in Southeast and East Asian countries have a non-negligible public health impact.

Key words

Air Pollution; Environment and public health; Epidemiology; Risk assessment

Introduction

A series of studies have reported that there is an association between exposure to air pollution (even at recent lower exposure levels) and adverse health outcomes, especially cardiopulmonary outcomes (1, 2). Based on this evidence, the World Health Organization (WHO) estimates that 3.7 million deaths were caused by exposure to ambient air pollution for 2012 and about 70% of these estimated deaths occur in the South-East Asia and the Western Pacific WHO regions (3). This WHO estimate was based on the air pollution exposure modelled using a combination of estimates from data provided by satellites, outputs from the global chemical transport model, and ground measurements. However, the modelled dataset has several weaknesses including time of estimation (i.e., some of the data date back several years) or accuracy of the model (3). Therefore, there is a need for collaboration with local governments that have access to local air pollution measurements to conduct health impact assessment (HIA) for Southeast and East Asian regions.

The results of several between-country collaborative HIA studies have been reported for Western countries(4-8). For example, the Apheis programme conducted an HIA of air pollution effects that included several European cities (4, 5, 7). The findings of this assessment indicated that current levels of air pollution in urban European cities have significant effects on public health.

Outdoor air pollution is an important public health problem in Asia (9). The characteristics of Asian populations and societies are different from Western counties (e.g., air pollution levels, city population densities, poverty levels, health status, and nutrition). A significant heterogeneity is present even among Asian countries. Separate HIA studies have been performed in several countries in Asia (10-12), but no results from collaborative studies on HIA have been published.

We conducted a collaborative HIA study that included participants from

Southeast and East Asian countries. We aimed to evaluate the health impacts of long-term exposure to particulate matter (PM). We calculated the number of long-term attributable cases, assuming that there is a causal relationship between PM and the observed health effects.

Materials and Methods

Study setting

We invited the member countries of the Air Quality Thematic Working Group of the Regional Forum on Environment and Health in Southeast and East Asia to join the project. The Regional Forum consists of 14 Southeast and East Asian member countries. The Forum's general objective is to facilitate the management of environmental health problems within and between countries by increasing the environmental health management capacity of each member country. In April 2012, we distributed a letter that invited the members of the Working Group to provide data on air pollution and other relevant variables for their cities with population sizes >1 million individuals, and for their capital cities. Seven out of the 14 countries provided data. However, the data received from Malaysia and Thailand were insufficient for the analysis (e.g., lacks mortality in specific cities or lacks necessary mortality information). The Philippines provided information for cities with population sizes <1 million (but >0.3 million), and we included these data in a separate analysis.

Information collected

We collected the following information for 2009 or the most recent year (if 2009 data were not available): characteristics of the selected cities (area and number of population), annual mortality, annual concentrations of PM at background stations, the number of background stations in each city, the intervals or periods of PM measurement, the method used for PM measurement, the conversion factor used for PM [e.g., from total suspended particulate (TSP) to PM <10 μm diameter (PM_{10}) or PM_{10}, to PM <2.5 μm diameter ($PM_{2.5}$)] (if available), and the quality assessment/quality control protocol used during the measurement. We also obtained data on life expectancy at birth in the most recent year and PM air quality standards for each country.

Annual concentrations of particulate matter

The PM data consisted of the variables $PM_{2.5}$, PM_{10}, suspended particulate matter (SPM), and TSP. Because we estimated the attributable number of cases caused by long-term exposure to PM_{10} and $PM_{2.5}$, we used the conversion factors to estimate these variables from other PM indicators (e.g., TSP, SPM) when they were available. Because none of the countries provided their own conversion factors, we used the following conversion factors for the analyses:

- $PM_{10} = 0.55 * TSP$ *(13)*
- $PM_{10} = 1.16 * SPM$ *(recorded at Air Quality Research Station in National Institute for Environmental Studies of Japan in 2012)*
- $PM_{2.5} = 0.6 * PM_{10}$ *(13)*

Annual mortality among individuals ≥ 30 years of age

The annual mortality data for individuals ≥ 30 years of age included total mortality, total mortality excluding external causes, cardiopulmonary mortality, and lung cancer mortality. The Philippines provided mortality data for the year 2005, but data from all other countries was for the year 2009. We selected these health outcomes so that our results could be compared to the results from the three studies that reported relative risk (RR) values that we used for this HIA (Table 1). RR values for the association between PM_{10} long-term exposure and all causes of mortality, and which did not include violent deaths and accidental deaths, were obtained from two large US studies (14, 15) . The HIA study conducted in Austria, France, and Switzerland provided a meta-analytical RR, which was based on two cohort studies (6). An updated analysis of the same US cohort study (16) provided an RR value for the association between $PM_{2.5}$ long-term exposure and all causes of mortality, including accidental deaths. We also included cardiopulmonary and lung cancer deaths in $PM_{2.5}$ long-term exposure because RR values were available from this US cohort study.

Statistical methods

We calculated the number of long-term attributable cases, assuming that there is a causal linear relationship between PM and the observed health effects. Following WHO air quality guidelines (17), we performed the HIA using the scenario of reducing the annual mean value of PM_{10} and $PM_{2.5}$ to the levels of 20 and 10 μg/m^3, respectively.

Our statistical model was from the formula developed by WHO (18) and was similar to the models used for previous HIA studies in Europe (6, 7).

Step 1

First, using the current (observed or estimated) exposure level (E) and the current health outcome frequency (Pe), we estimated the health outcome frequency (Po) expected at the reference exposure level (B) (i.e., 20 μg/m^3 for PM_{10} and 10 μg/m^3 for $PM_{2.5}$):

$$Po = Pe/\{1+[(RR-1)(E-B)/10]\},$$

where

Po = the expected health outcome frequency at the reference exposure level

Pe = the observed/current health outcome frequency

RR = the relative risk per 10 μg/m^3 increase

E = the observed or estimated current PM_{10} or $PM_{2.5}$ exposure level

B = the reference exposure level

Step 2

Using the estimate of Po, we calculated the attributable number of cases (D10) per 1,000,000 persons for an increase in exposure of 10 μg/m^3:

D10 = 1,000,000*Po* (RR-1)

where

D10 = the number of additional cases per million for an increase in exposure of 10 μg/m^3

To estimate a range of effect, we used the upper and lower 95% confidence interval (CI) values of RR, and estimated the upper and lower 95% values for D10.

Step 3

Using the estimated value for D10, the observed or estimated PM_{10} or $PM_{2.5}$ concentrations, the reference exposure level, and the population size, we calculated the total number of cases attributable to long-term exposure to PM_{10} or $PM_{2.5}$. We also estimated the upper and lower 95% values for the attributable cases according to the upper and lower 95% values of D10.

All of the calculations were performed using Microsoft Excel 2010 spread sheet software (Microsoft Corporation, Redmond, WA, USA).

Results

In total, we included data from 27 cities from Japan, the Philippines, the Republic of Korea, Singapore, and Vietnam in the main analysis. The total number of population more than or equal to 30 years old in the cities was 50,756,699. A description of the characteristics of the 27 cities from the five countries is presented in Table 2. Life expectancy at birth in the most recent year (in 2010 except Viet Nam (2009)) in the selected countries ranged from 66 (men) and 73 (women) years in the Philippines to 79 (men) and 86 (women) years in Japan. A description of the measurement methods and the results for observed annual concentrations of PM are also presented. Using the conversion factors, we estimated the annual mean concentrations of $PM_{2.5}$ and PM_{10} for the cities for which these data were not available. The annual mean (observed or estimated) concentrations ranged from 15.1 to 173.0 $\mu g/m^3$ for PM_{10} and from 10.8 to 103.8 $\mu g/m^3$ for $PM_{2.5}$, respectively (Figure 1).

The results for each city for the long-term impacts of chronic exposure to PM_{10} and $PM_{2.5}$ are presented in Figure 2 and in online Table 1. The impact owing to all-cause and to cardiopulmonary mortality was the greatest in Seoul, Korea, followed by Ho Chi Minh City, Vietnam (for all-cause mortality), and Tokyo, Japan (for cardiopulmonary mortality). The impact from lung cancer mortality was the largest in Ho Chi Minh City, followed by Seoul.

In total, a reduction in long-term exposure to PM_{10} and $PM_{2.5}$ to the levels recommended by WHO air quality guidelines would have postponed a total of approximately 37,000 early deaths in the 27 cities (Table 3), which corresponds to 8–9% of all causes of mortality (online Table 1). Among the 37,000 postponed deaths, one-third of them were associated with cardiopulmonary mortality and one-ninth of them were associated with lung cancer mortality.

We also included data from eight Philippines cities (population sizes <1 million) in a separate analysis; thus, a total of 54,793,747 individuals (≥ 30 years of age) that resided in 35 cities were included (online Table 2). The exposure distribution did not change substantially. The annual mean (observed or estimated) concentrations ranged from 15.1 to 173.0 μg/m^3 for PM_{10} and from 9.9 to 103.8 μg/m^3 for $PM_{2.5}$, respectively (online Figure 1). The results for the estimates for each city of the long-term impacts of exposure to PM_{10} and $PM_{2.5}$ are presented in online Figure 2 and online Table 3. Reducing the long-term exposure to PM_{10} and $PM_{2.5}$ to the levels recommended by the WHO air quality guidelines would have postponed a total of approximately 40,000 deaths in the 35 cities (Online Table 4).

Discussion

Based on the linear relationship between PM and the health effects, we estimated the long-term impacts of chronic exposure to PM_{10} and $PM_{2.5}$ in 27 Southeast and East Asian cities. We could not include all of the cities located in the member countries of the Regional Forum. However, the results indicated that complying with the WHO guideline corresponds to approximately 37,000 postponed deaths, even at the current PM_{10}/$PM_{2.5}$ exposure levels. This study is the first to perform a collaborative HIA in Asia.

As reported by WHO (17), PM exposure levels vary widely in Asian cities (e.g., estimated concentrations of $PM_{2.5}$ vary from 10.8 μg/m^3 in Sapporo, Japan, to 103.8 μg/m^3 in Caloocan City, Philippines). However, the results of this HIA indicated that there was a large public health impact in the cities with relatively high concentrations of air pollution (e.g., Ho Chi Minh) and in the cities with large populations sizes, but low or moderate exposure levels among the 27 cities included in the present study (e.g., Seoul and Tokyo). This finding indicates that the public health effect of air pollution should not be ignored for urban cities with relatively low to moderate exposure levels.

When estimating the long-term impacts, we used the values for slope (i.e., RRs) estimated from two large US cohort studies (14, 15, 19), because these RR values were used in previous HIAs (6, 7, 12). The findings from these two studies were re-analyzed to confirm their validity (20) and were also supported by the results of subsequent studies in other regions of the world (1, 21-23). In addition, these RR values (Table 1) were close to recent RR values for $PM_{2.5}$ provided by the WHO Regional office for Europe: RR of 1.066 (95%CI: 1.040 – 1.093) per 10 $\mu g/m^3$ based on 14 studies for all-cause mortality and RR of 1.10 (95%CI: 1.05 – 1.15) per 10 $\mu g/m^3$ based on 14 studies for cardiovascular mortality (24). Therefore, these RR values are considered to be valid estimates.

The extrapolation of RRs values to our target population was a concern. Potential effect modifications may exist because of differences between Asian and Western counties (e.g., city population densities, poverty, health status, and nutrition). PM composition in Asian cities may be different from PM composition in Western cities. However, the results from recent studies performed in Asian countries also revealed that long-term exposure to air pollution results in cardiopulmonary disease or lung cancer, with magnitude of effect estimates that were similar to our estimates (25, 26). This agreement between study results supports our decision to extrapolate the RR values to our study population.

We did not have a prearranged protocol for exposure assessment. We collected information on exposure concentrations obtained from monitoring stations. Constituents of PM may also differ within cities. In addition, we have three cities with only 1 monitoring station (Caloocan City, City of Manila, and Davao in Philippines). We thus may have under- or over-estimated the number of attributable cases for some cities.

Although we used International Classification of Disease codes to collect information on causes of mortality for each country, medical protocols used for disease diagnosis may differ between or within countries. However, this type of outcome misclassification does not affect our conclusion for total mortality.

Finally, caution should be used when equating attributable cases and preventable cases, because this assumption does not account for competing risks. The reduction of risk may increase the relative importance of other causes of death. HIA studies that include an assessment of competing risks would be necessary.

In conclusion, we conducted a collaborative HIA study in 27 Southeast and East Asian cities and estimated the long-term impacts of chronic exposure to PM_{10} and $PM_{2.5}$. If current air pollution levels could be reduced to be consistent with WHO air quality guidelines, 8–9 % of all-cause mortality, or about 37,000 deaths, could be postponed. The current air pollution levels in Southeast and East Asian countries have a non-negligible public health impact in cities with high levels of air pollution and in cities with relatively low to moderate levels of air pollution.

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Figure legend.

Figure 1a. Annual mean concentrations of PM_{10} (measured or estimated).

Figure 1b. Annual mean concentrations of $PM_{2.5}$ (measured or estimated).

Figure 2a. Number of preventable early deaths associated with a reduction in annual mean values of PM_{10} to 20 μg/m^3.

Figure 2b. Number of postponed deaths associated with a reduction in annual mean values of $PM_{2.5}$ to 10 μg/m^3.

Figure 2c. Number of postponed cardiopulmonary deaths associated with a reduction in annual mean values of $PM_{2.5}$ to 10 μg/m^3.

Figure 2d. Number of postponed lung cancer deaths associated with a reduction in annual mean values of $PM_{2.5}$ to 10 μg/m^3

Table 1. Health outcome definitions, relative risks, source of relative risks, and reference values.

Exposure	Health outcome	ICD10; ICD9	RR per 10 μg/m3 (95%C.I.)	Source of RR	Reference* (μg/m3)
PM_{10}	All-cause mortality ≥30years (excluding violent death or accidents)	A00-R99; 001~799	1.043 (1.026-1.061)	Dockery DW et al 1993 Pope CA et al 1995	20
$PM_{2.5}$	All-cause mortality >30years	A00-Y98; 001~999	1.06 (1.02-1.11)	Pope CA et al 2002	10
	Cardiopulmonary mortality	I10-I70/J00-J99; 401~440/460~519	1.09 (1.03-1.16)	Pope CA et al 2002	10
	Lung cancer	C33-C34	1.14 (1.04-1.23)	Pope CA et al 2002	10

*We conducted the health impact assessment for the scenario of reducing the annual mean value of PM_{10} and $PM_{2.5}$ to these references. Source of reference: WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide Global update 2005

CI, confidence interval; ICD, International Classification of Diseases; PM_{10}, PM less than 10 μm in diameter; PM2.5, PM less than 2.5 μm in diameter; RR, relative risk

Table 2. Characteristics of the study areas, measurement methods, and concentrations of particulate matter (PM) in 27 Southeast and East Asian cities.

City	Country	Area (km^2)	Population ≥ 30 years old		No. of PM stations in the city	Interval	Method	**Concentrations ($\mu g/m^3$)**				
			Number	Year				**TSP**	**PM_{10}**	**SPM**	**$PM_{2.5}$**	**Year**
Busan	Republic of Korea	767.0	2,282,320	2009	17	hourly	β-ray-absorption		49.35			2009
Caloocan City	Philippines	53.3	1,489,040	2010	1	Once a week	Manual		173			2011
City of Manila	Philippines	38.6	1,652,171	2010	1	Once a week	Manual	101	53			2011
Daegu	Republic of Korea	884.0	1,541,367	2009	11	hourly	β-ray-absorption		48.18			2009
Daejeon	Republic of Korea	540.0	883,411	2009	7	hourly	β-ray-absorption		43.42			2009
Davao	Philippines	2444.0	1,449,296	2010	1	Once a week	Manual	44				2011
Fukuoka	Japan	341.0	934,081	2009	16	continuous	β-ray-absorption			27		2009
Gwangju	Republic of Korea	501.0	832,753	2009	7	hourly	β-ray-absorption		46.14			2009
Hanoi	Vietnam	3328.9	3,039,670	2009	9	continuous	Orthogonal Light Scattering (90^o)	108.3	85.51		46.43	2009
Hiroshima	Japan	905.1	795,341	2009	11	continuous	β-ray-absorption			26.2		2009
Ho Chi Minh City	Vietnam	2095.6	3,372,870	2009	8	continuous	Orthogonal Light Scattering (90^o)	270	78.7			2009
Incheon	Republic of Korea	1029.0	1,650,292	2009	15	hourly	β-ray-absorption		60.07			2009
Kawasaki	Japan	142.7	959,820	2009	18	continuous	β-ray-absorption			22.3	17.5	2009
Kitakyushu	Japan	487.7	699,003	2009	19	continuous	β-ray-absorption			27		2009
Kobe	Japan	552.2	1,046,448	2005	21	continuous	β-ray-absorption			23.2		2009
Kyoto	Japan	827.9	981,620	2009	15	continuous	β-ray-absorption			20		2009
Nagoya	Japan	326.4	1,550,903	2009	27	continuous	β-ray-absorption			25.7	16.7	2009
Osaka	Japan	222.3	1,859,430	2009	24	continuous	β-ray-absorption			25.9	17.5	2009
Quezon City	Philippines	166.2	2,761,720	2010	4	Once a week	Manual	78.3	67.3		41.62	2011 (2010 for PM_{10})

Saitama	Japan	217.5	833,804	2008	17	continuous	β-ray-absorption		25.2		2009
Sapporo	Japan	1121.1	1,712,568	2009	9	continuous	β-ray-absorption		13	10.8	2009
Sendai	Japan	783.5	686,154	2009	17	continuous	β-ray-absorption		18.1		2009
Seoul	Republic of Korea	605.0	6,409,185	2009	27	hourly	β-ray-absorption	54.89			2009
Singapore	Singapore	710.3	2,287,100	2009	10	hourly	TEOM , β-ray-absorption	77		19	2009
Tokyo	Japan	621.0	5,853,976	2005	57	continuous	β-ray-absorption		25.5	14.9	2009
Ulsan	Republic of Korea	1059.0	664,162	2009	13	hourly	β-ray-absorption	48.92			2009
Yokohama	Japan	437.4	2,528,194	2009	29	continuous	β-ray-absorption		25.3		2009

PM, particulate matter; TSP, total suspended particulate matter; PM_{10}, PM less than 10 μm in diameter; SPM, suspended particulate matter; $PM_{2.5}$, PM less than 2.5 μm in diameter

Table 3. Total annual health impacts of PM_{10} and $PM_{2.5}$ in 27 Southeast and East Asian cities.

Exposure	Reference	Health outcome	Annual health impacts (cases) (95%CI)
PM_{10}	20 μg/m^3	All-cause mortality ≥ 30years (excluding violent death or accidents)	36585 (22121-51901)
$PM_{2.5}$	10 μg/m^3	All-cause mortality ≥ 30years	36565 (12188-67037)
		Cardiopulmonary mortality	12649 (4216-22487)
		Lung cancer	4101 (1171-6738)

CI, confidence interval; PM_{10}, PM less than 10 μm in diameter; $PM_{2.5}$, PM less than 2.5 μm in diameter

Figure 1a

Annual mean concentrations of PM_{10} (measured or estimated)

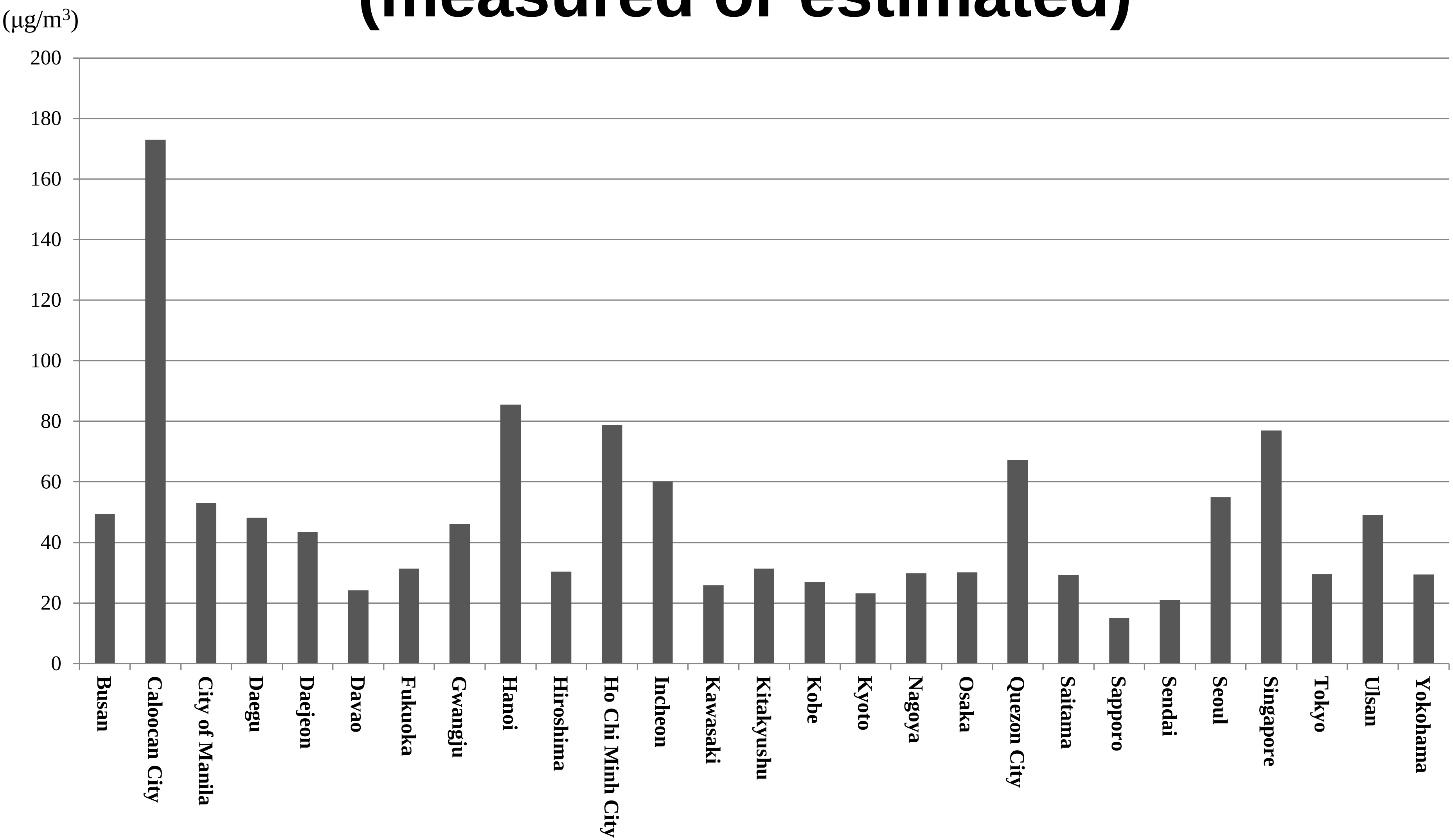
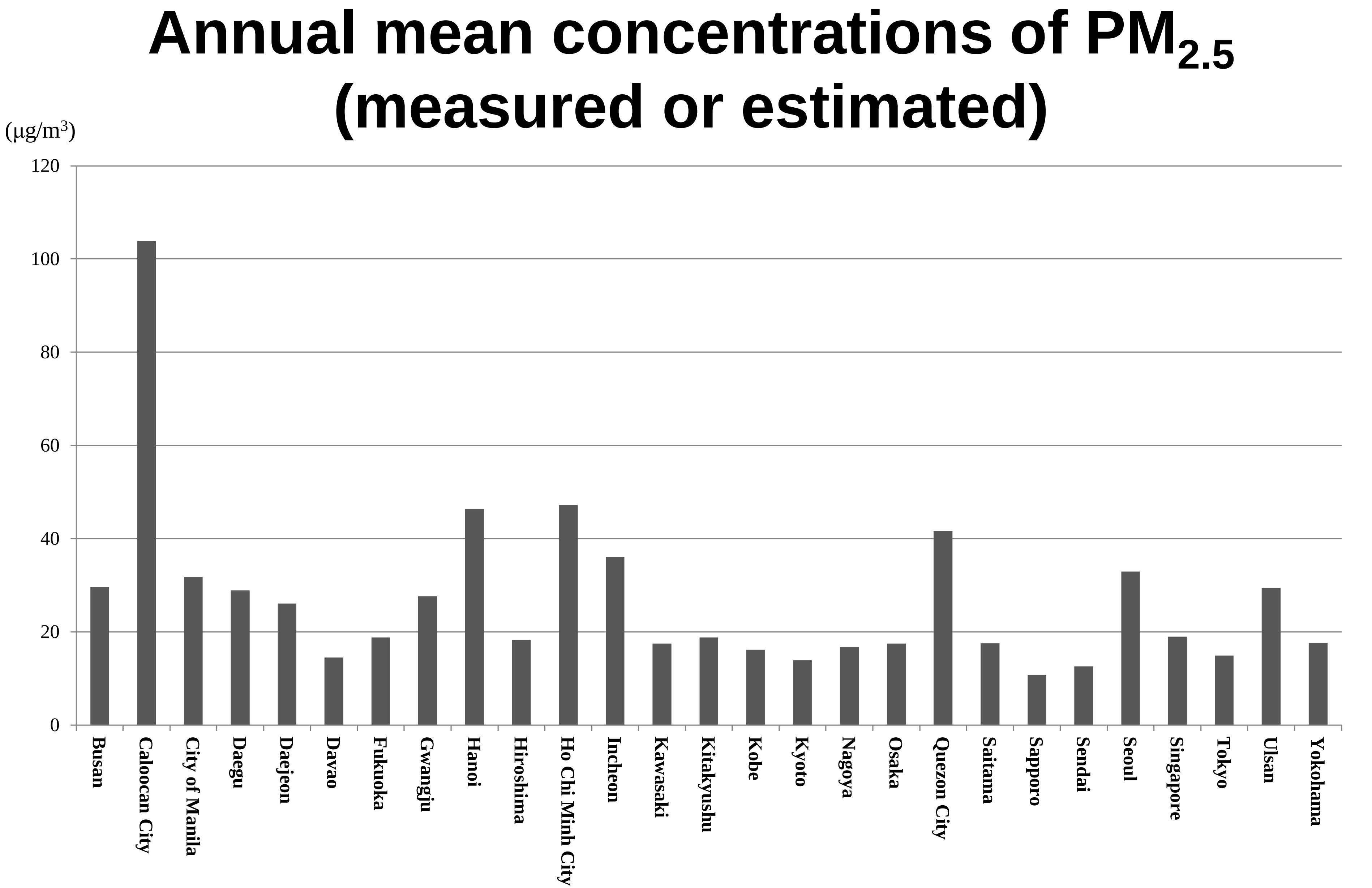


Figure 1b



Annual mean concentrations of PM2.5
(measured or estimated)
(μg/m3)
120
100
80
60
40
20
0
Busan
Caloocan City
City of Manila
Daegu
Daejeon
Davao
Fukuoka
Gwangju
Hanoi
Hiroshima
Ho Chi Minh City
Incheon
Kawasaki
Kitakyushu
Kobe
Kyoto
Nagoya
Osaka
Quezon City
Saitama
Sapporo
Sendai
Seoul
Singapore
Tokyo
Ulsan
Yokohama

Figure 2a

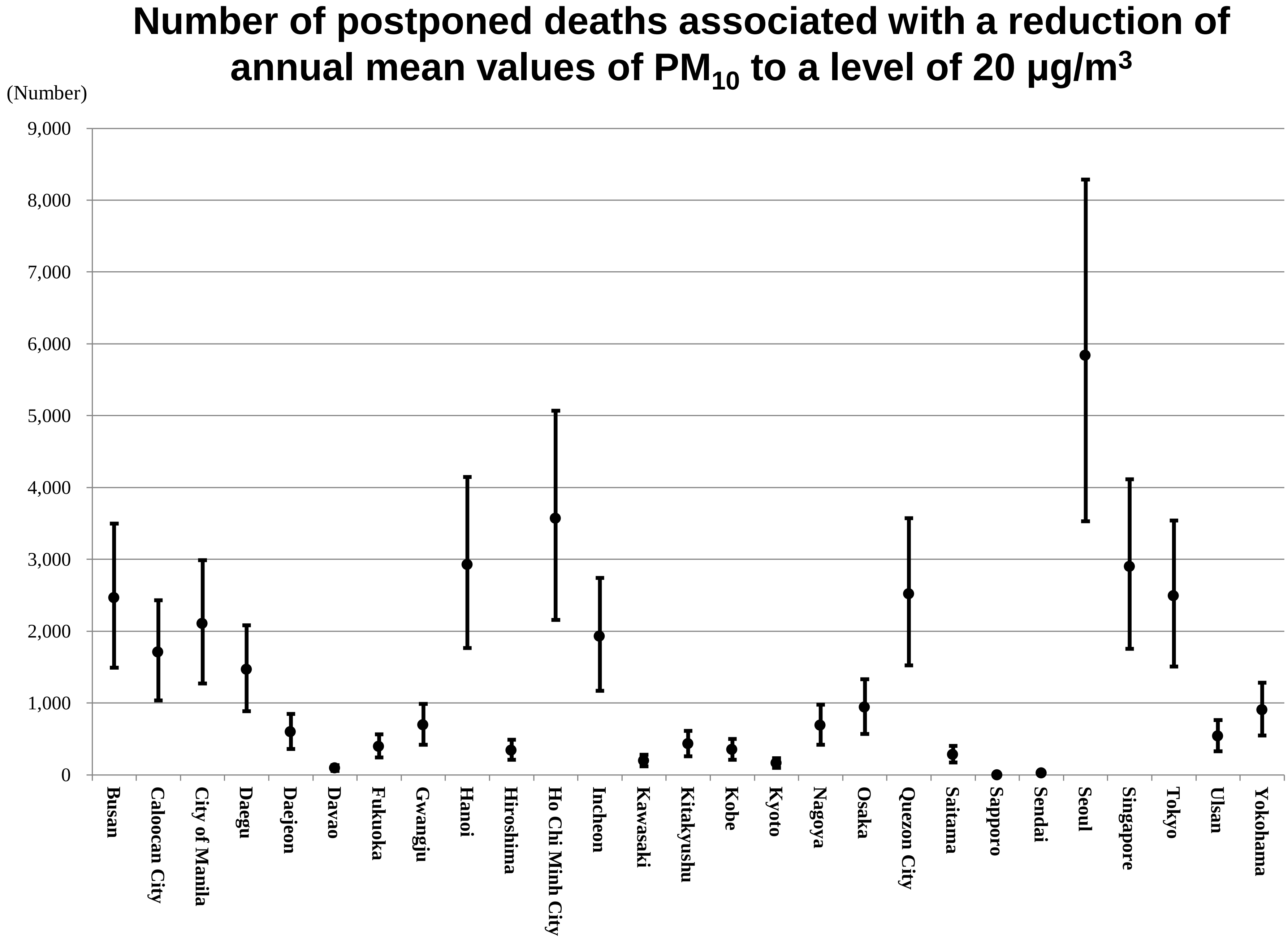

Number of postponed deaths associated with a reduction of annual mean values of PM10 to a level of 20 μg/m3
(Number)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Busan
Caloocan City
City of Manila
Daegu
Daejeon
Davao
Fukuoka
Gwangju
Hanoi
Hiroshima
Ho Chi Minh City
Incheon
Kawasaki
Kitakyushu
Kobe
Kyoto
Nagoya
Osaka
Quezon City
Saitama
Sapporo
Sendai
Seoul
Singapore
Tokyo
Ulsan
Yokohama

Figure 2b

Number of postponed deaths associated with a reduction of annual mean values of $PM_{2.5}$ to a level of 10 μg/m^3

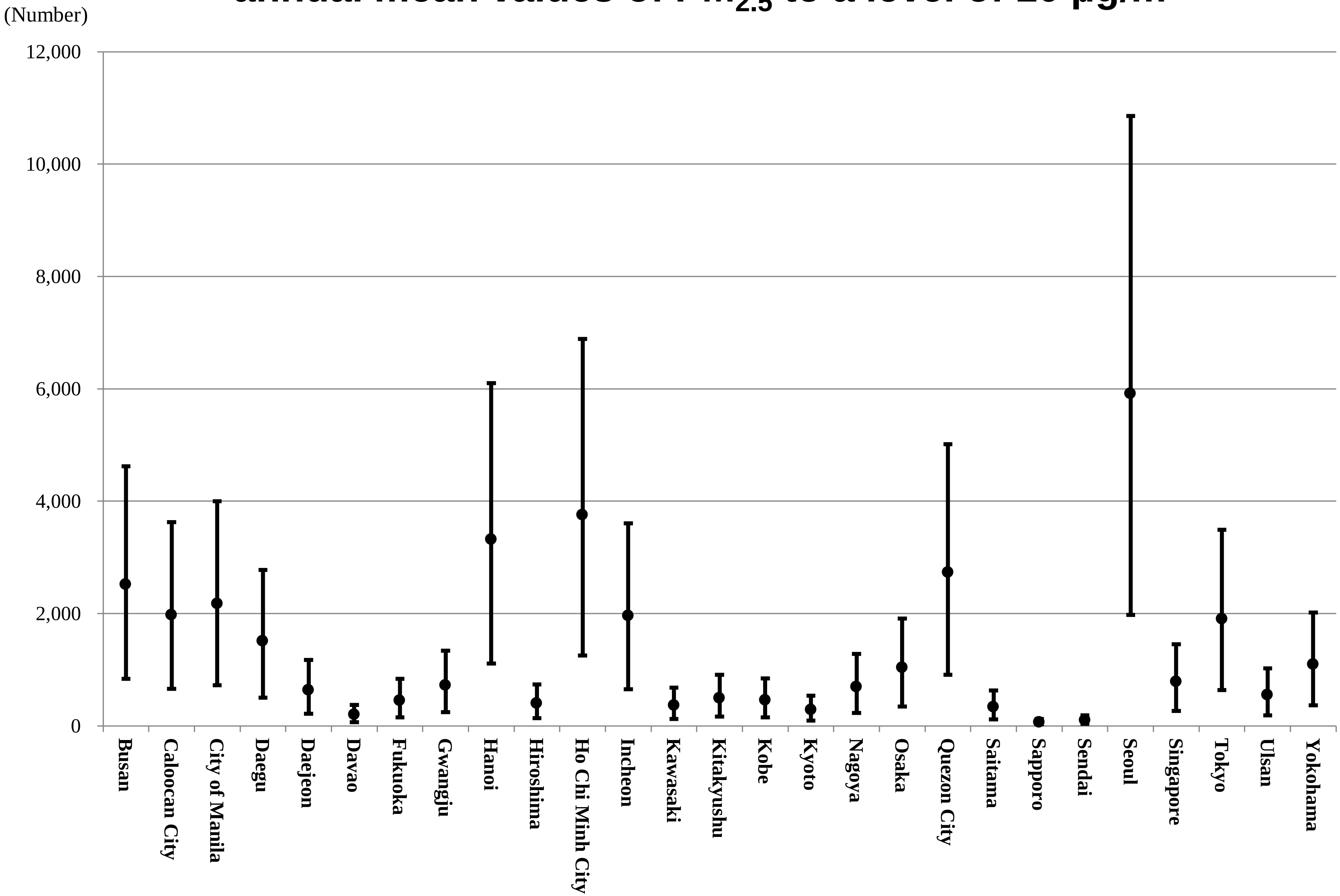
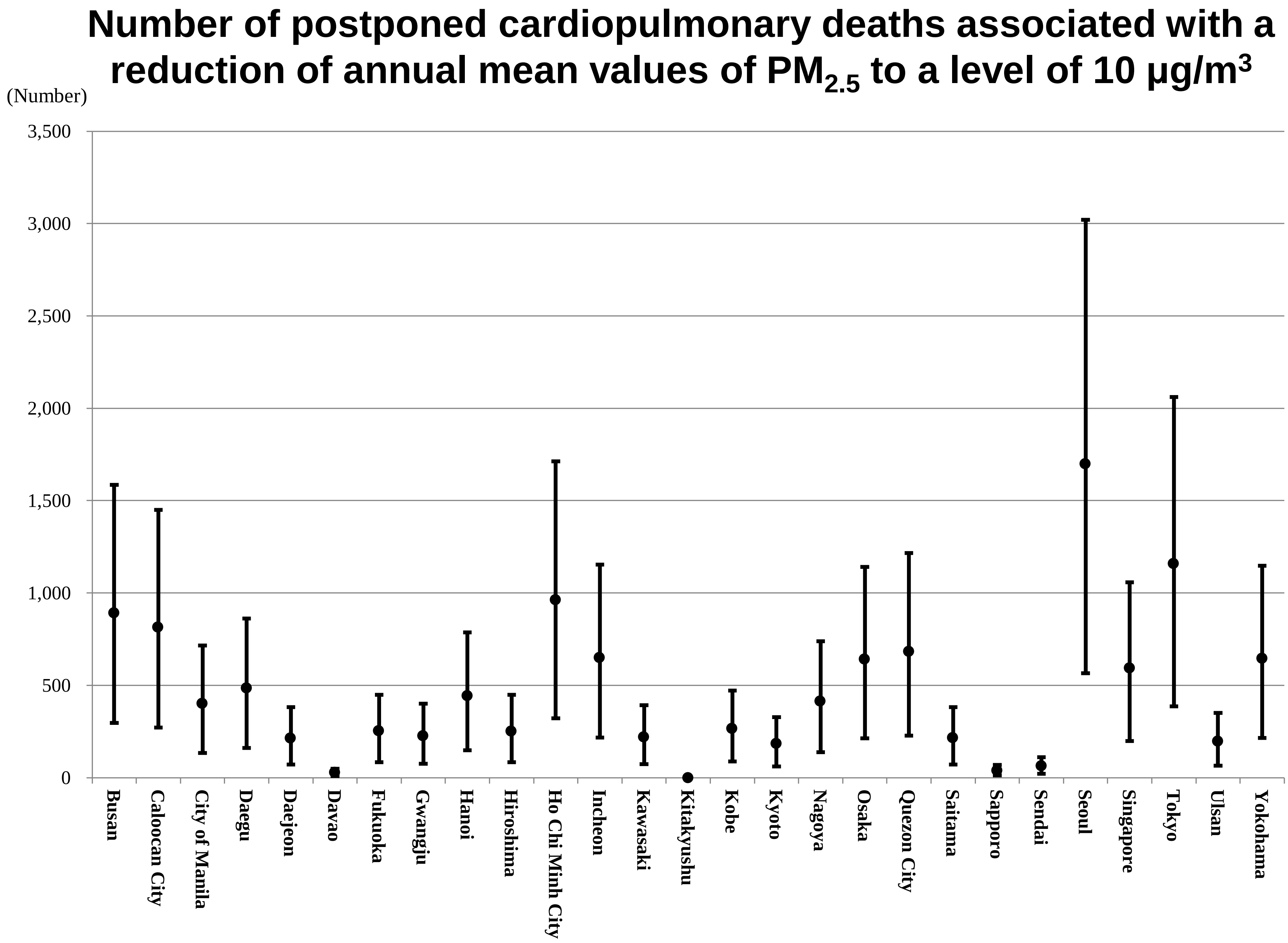
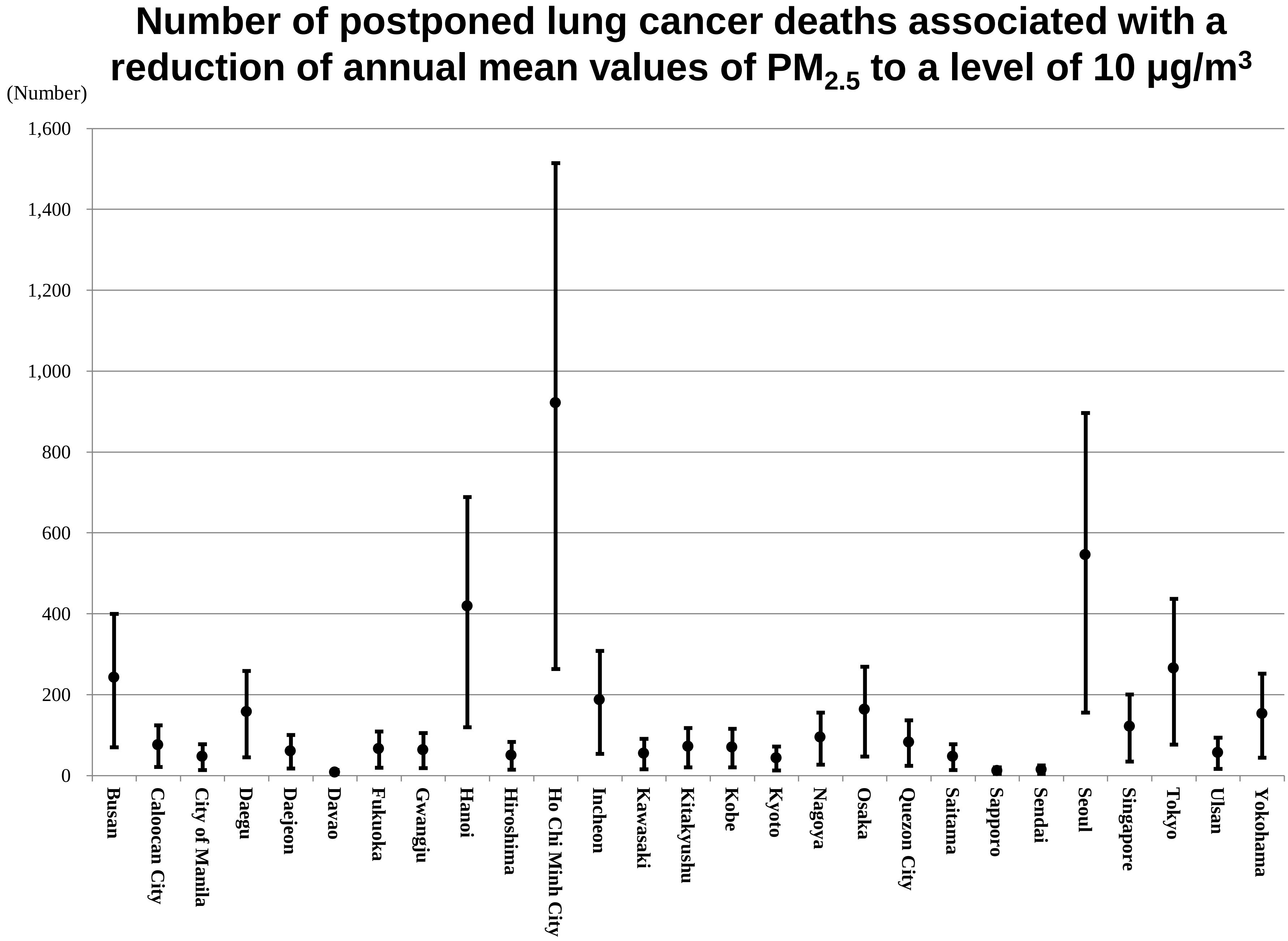


Figure 2c



Number of postponed cardiopulmonary deaths associated with a reduction of annual mean values of $PM_{2.5}$ to a level of 10 μg/m^3
(Number)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Busan
Caloocan City
City of Manila
Daegu
Daejeon
Davao
Fukuoka
Gwangju
Hanoi
Hiroshima
Ho Chi Minh City
Incheon
Kawasaki
Kitakyushu
Kobe
Kyoto
Nagoya
Osaka
Quezon City
Saitama
Sapporo
Sendai
Seoul
Singapore
Tokyo
Ulsan
Yokohama

Figure 2d


Number of postponed lung cancer deaths associated with a reduction of annual mean values of $PM_{2.5}$ to a level of 10 μg/m^3
(Number)
1,600
1,400
1,200
1,000
800
600
400
200
0
Busan
Caloocan City
City of Manila
Daegu
Daejeon
Davao
Fukuoka
Gwangju
Hanoi
Hiroshima
Ho Chi Minh City
Incheon
Kawasaki
Kitakyushu
Kobe
Kyoto
Nagoya
Osaka
Quezon City
Saitama
Sapporo
Sendai
Seoul
Singapore
Tokyo
Ulsan
Yokohama